GEOGRAPHICAL NOTES.

The Royal Geographical Society's *soirée* took place on the 17th inst. at the South Kensington Museum, when the guests were received by the President and Council. The attendance was very great. The attractions of the evening included selections by the Coldstream Guards band, solo and part singing in the lecture theatre, and an exhibition by the dioptric lantern of maps and views, with explanation by Mr. H. J. Mackinder.

Some interesting particulars as to the present state of the Marshall Islands are published in the *Deutsches Kolonialblatt*. The population is estimated at 15,000 aborigines, and about 100 whites. Cocoa-nuts and copra are the staple exports; pandanus, breadfruit, and arrowroot being cultivated on a small scale. The natural grass is not suitable for pasture, but with the introduction of foreign grass seed, cattle and sheep breeding may become profitable. Taking into consideration the character of the soil and the density of population, the future of the German protectorate in the Marshall Islands is acknowledged not to be very bright, although the authorities hope that it may become of enhanced importance for trade with Germany.

The *National Geographic Magazine* has just published an account by Dr. Charles Willard Hayes of the expedition through the Yukon district in 1891, conducted by Mr. Schwatka on behalf of a syndicate of American newspapers. Entering by the Yaku inlet, the expedition made its way by canoe, as soon as the ice disappeared, up the Yaku River; thence it crossed the watershed, and continued on Lake Ahklen and the Teslin River to Lewes River, a tributary of the Yukon. A traverse survey was made all the way, and the route laid down in a serviceable manner, though of course without the precision of an actual survey. This district has been several times visited by prospectors, and parts of it mapped by previous explorers; but the expedition opened up, probably for the first time, the unknown region extending from the Yukon to the St. Elias Mountains. Across this blank, usually filled in hypothetically on maps, the expedition surveyed a line of 330 miles, from Selkirk, on the Yukon, to the junction of the Chittenah and Nizzenah rivers. The report gives a clear summary of the topography, drainage, orographic system, and geology of the region traversed.

Prince Henry of Orleans has returned to France after a difficult journey from the Upper Mekong, through the Shan States and Siam, where he reached the coast at Bangkok.

Captain W. G. Stairs, whose quiet heroism in Stanley's Emin Relief Expedition was brought prominently before the world two years ago, has fallen a victim to African travel. He was born at Halifax, Nova Scotia, in 1863, and educated at Merchiston Castle School, in Edinburgh, subsequently studying at the Royal Military College, Kingston, Ontario. After his training in Canada he spent some time in New Zealand as a civil engineer; but obtaining a commission in the Royal Engineers, he came to Chatham, and completed his military training. When the Emin Relief Expedition was fitting out in 1887, he volunteered to accompany it; and from the first he impressed Mr. Stanley as a man of exceptional qualities—an opinion strengthened by the strict obedience and absolute loyalty which distinguished him throughout the trying years that followed. As the only member of the advance party (Dr. Parke excepted) who had much interest in scientific matters, Captain Stairs would undoubtedly have made large additions to knowledge had it not been for the imperative exclusiveness of his work as an officer. He was selected for the best piece of geographical exploration attempted during the expedition—the ascent of Mount Ruwenzori. Last year Lieutenant Stairs was promoted to a captaincy, but the fatal attraction of Africa led to his resignation in order to accept command of the Katanga Company's expedition. This Company was formed in Belgium to administer and exploit the south-eastern corner of the Congo Free State, in what is known as Msidi's country. Stairs left Zanzibar last summer, crossed to Lake Tanganyika by the familiar trade route *vià* Tabora, and reached Mpala on October 31, after a remarkably rapid and easy journey. Thence he traversed Msidi's country in the rainy season, where he suffered much from fever, but succeeded in reaching the Ruo on May 13, and arrived at Vicenti, near the mouth of the Zambesi, on June 3. But at Chinde, just as the expedition had overcome all the difficulties of the way, and only waited for a passage to Zanzibar, Captain Stairs died. This sad event has removed from the list of African travellers one of the bravest, most prudent and modest of young explorers.

THE MICROSCOPE'S CONTRIBUTIONS TO THE EARTH'S PHYSICAL HISTORY.[1]

Men will have forgotten much when the second half of this nineteenth century is no longer remembered. Whatever may have been its faults, it has no rival in the past history of the world as an epoch of scientific progress. This progress has been largely due to the felicitous co-operation of the mind of the student with the skill of the craftsman in the more perfect construction of instruments of research. By them darkness has been made visible; the opaque, translucent; the unseen, conspicuous; the inert, sensitive; silence, vocal. A thousand methods of experiment, tests of the most delicate nature, have been devised, so that vague conjecture has been replaced by exact knowledge, and hypothesis by demonstration. In such an epoch it may seem a little fanciful to select any one term of years as exceptionally fruitful; but it is remarkable that in the first decade of this half-century, science was enriched by three contributions, each of which has led to consequences of far-reaching import. In 1858 Charles Darwin and Alfred Russel Wallace announced simultaneously the conclusions as to the origin of species at which they had independently arrived, and the well-known book by the former author appeared in the following year. They thus formulated the results of protracted investigations and patient experiments with the simpler appliances of earlier days. They subjected, more strictly than ever before, the facts of nature to an inductive treatment, and thus lent a new impulse to biological science. Their hypothesis gave a definite aim to the researches of students, and kindled an unquenchable flame of intellectual activity. In 1860, Bunsen and Kirchoff announced the results of applying the spectroscope to problems in chemical analysis. By means of this instrument not only have investigations attained a precision hitherto impossible, but also the student, no longer cribbed, cabined, and confined, to the limits of the earth, can question the stars in their courses, and bid nebulæ and comets reveal the secrets of their history. Lastly—though the problem be in a humbler sphere, dealing with neither the immensities of stellar physics nor the mystery of life—Henry Clifton Sorby, in 1856, described the results of microscopic investigations into the structures of minerals and rocks. Strictly speaking, indeed, the method was not wholly novel. So long since as 1827, William Nicol, of Edinburgh, had contrived to make sections of fossil wood sufficiently thin for examination under the microscope; but the device, so far as I know, had not been generally applied, or its wide possibilities apprehended.

You have heard in this place on former occasions of the triumphs of the spectroscope in extra-terrestrial space; of the revelations of the microscope in regard to the least and lowest forms of life; I have ventured to ask your attention to-day to the work of that instrument in a humbler and more limited field—the constitution and history of the earth's crust. My task is beset with difficulties. Did I address myself to experts, these would be but a small portion of my audience; if I speak to the majority, it will be hard to make intelligible a subject bristling with technicalities. Moreover, as this building is so ill-suited for the usual methods of illustration, I have decided to dispense with diagrams or lantern slides, and will try to tell, in the plainest language at my command, the conclusions as to the genesis of rocks and the earlier history of the earth to which the researches of the last few years seem to be tending.

I have excluded from my story investigations which bear upon the biology of the past, though the work of the microscope in this field has not been less fruitful or interesting, because these are more widely known. Moreover, they have not specially engaged my attention, and there is, I believe, an expectation amounting to an unwritten law, that whoever has the honour to occupy my present position should be so far egotistical as to talk of the particular plot, however small it may be, on which he has laboured in the garden of science. So I will crave the indulgence of the few experts present, and the patience of the majority of my audience, while I try to tell the story of microscopical research into the history of the earth's crust.

Twenty years ago, I believe, not half that number of geologists in the British Isles made any real use of the microscope. Now they may be counted by scores, not only in the United Kingdom, but also in every civilized land. Obviously in a science so new, in a research which is extending so rapidly, much diversity of opinion must exist on some theoretical questions. Into the details of controversies it is not my purpose to enter; but I shall content myself with indicating the conclusions to which I have been led in the time which the many inevitable duties of life permitted me to devote to this branch of geology.

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[1] The Rede Lecture for 1892, delivered before the University of Cambridge, by T. G. Bonney, Sc.D., F.R.S.

Before doing this it may be well to indicate very briefly the mode in which the microscope is applied to the examination of rocks. Commonly it is as follows: slices, cut by the lapidary's wheel from minerals or rocks, are ground down smoothly till they are about one one-thousandth part of an inch thick, and are then mounted on glass. By this means most minerals, including the great majority of the ordinary constituents of rocks, become translucent, if not transparent. They are then examined under a specially-constructed microscope, fitted with Nicol's prisms and other contrivances for optical tests. Occasionally also certain chemical tests can be applied. To what extent an object is magnified depends on the nature of the investigation. A very minute crystal can sometimes be studied, under favourable circumstances, when enlarged to at least 800 diameters; but in ordinary cases, where the chief constituents of a rock and their mutual relations are the object of research, a magnification of from 50 to 100 diameters is commonly the most advantageous. Sands, clays, and incoherent materials can be readily studied by mounting them temporarily or permanently on glass; sometimes, also, good work can be done, and time saved, by crushing up fragments of minerals and of rocks, and by treating the powder thus obtained in the same way. Investigations, which promise to throw light on the problem of the development of minerals, have been recently made by examining the insoluble residues of those rocks which are chiefly composed of carbonates. Solutions of different specific gravities have proved very useful in the determination of the mineral constituents of a rock, which are sorted out by them, as by a strainer, from a sand, mud, or a powdered mass, so that each kind can be studied separately either by microscopical or by chemical analysis.

The subject evidently, in process of time, tends to divide itself into two branches: the one concerned mainly with the characters of the individual constituents of a rock, the other with the wide problem of their mutual relations, or, in other words, with the history of the rock-mass: branches properly denoted by the words *petrography* and *petrology*, though these terms are often confused. The former is more strictly a department of mineralogy; the latter a department of geology. This it is of which I chiefly speak to-day; this it is in which the most marked advances have been recently made.

How great these have been may be more readily appreciated if I mention a few matters, concerning which, even a quarter of a century since, great uncertainty prevailed. Though it was then generally admitted that one great group of rocks, such as clays, sandstones, limestones, &c., were sediments, and that another great group, the rocks called igneous, had solidified in cooling from a fused condition; the origin of a third, and by no means unimportant group, the crystalline schists and gneisses—the metamorphic rocks, as they were commonly called—was considered very doubtful. Many geologists also believed that not a few igneous rocks had been once sediments, like those in the first group, which had been subsequently fused or "digested" by the combined action of heat, water, and pressure. Thus it was supposed that clays and felspathic sandstones could be traced through various stages till they became granite, and rocks of the most diverse chemical composition could be transmuted one into the other. The province of metamorphism was the fairy-land of science; it needed but a touch of the magic wand, and, like Bottom the weaver, a rock was at once "translated." It would be easy, were it worth while, to enumerate instance after instance of these alleged transmutations, every one of which has been proved to be groundless. No doubt, even at the time named, these assertions were questioned by some geologists, but that they could be made so confidently, that they could be inculcated by the official representatives of geology in this country, shows the hopeless confusion into which petrology had fallen.

By means of the microscope also much light has been thrown upon the history even of the better known rocks. The classification of the igneous group has been simplified, and the relations of its several members have been determined. The microscope has dispelled many an illusion, and reduced a chaos to order. In regard to the sedimentary group, it often has determined the true nature of their constituents, and has suggested the sources from which they have been derived or the agents by which they have been transported. Thus, through its tube, we have been enabled, not only to gaze at the most intimate structure and composition of rock-masses, but also to catch glimpses of the earth's physiography in ages long before the coming of mankind.

But in speaking of the services rendered by the microscope, I must not forget a needful caution. If the instrument be employed for petrological rather than petrographical purposes, it must never be divorced from work in the field. No training in the laboratory, however complete, no research in a library, however laborious, can of themselves make a petrologist. No question can be completely mastered, unless it be also studied in the field; nay, even the specimens for examination under the microscope, as a rule, should be collected by the student himself, and the characters and relationships of the rock-masses from which they are detached should be carefully noted. It was said, on no mean authority, some fifty years since, that, in the education of a geologist, travel was the first, the second, and the third requisite. Perhaps the statement, like most epigrams, was somewhat one-sided, but the truth in it has not been diminished by the increased perfection of our instrumental methods. In petrology, the chimæras of the home-keeping student of the laboratory have been, and still are, as hurtful to progress, as the dreams of the peripatetic geologist, whose chief appliances are a stout pair of legs and a hammer.

This, then, was the problem which, some thirty years since, presented itself to geologists who were interested in petrology. Here are two groups of rocks, the sedimentary and the igneous. The origin of these we may be said to know, but as to that third group, which, though not as large, is far from unimportant—what is its history? what are its relations to the other two? The records of its rocks at present are illegible. Is there any hope that success will reward the attempt to decipher them? Time and perseverance have given an answer, and though much is still uncertain, though much remains to be done, some real progress, in my opinion, has been made. As the stones sculptured of old by the hand of man are yielding up their secrets, as the hieroglyphs of Egypt and the cuneiform characters of Assyria are telling the tale of the conquerors whose bones are dust, as the tongues of the children of Heth, and of the black-headed race of Accad, are being learnt anew, so the records of the rocks, wherein no trace of life is found, are being slowly, painfully, but ever more surely deciphered, and knowledge grows from year to year.

To obtain success the problem must be attacked in the following way. As the first step, the two great groups already mentioned, the origin of which is known, must be thoroughly studied. The examples selected must be nearly or quite unaffected by any agent of change, such as heat, water, and pressure. Among the specimens representative of the sediments, the materials must range from fine to coarse—for the grains in the latter serve also as samples of the rocks from which they have been broken, and suggest their own inferences. Among the igneous rocks, types ranging from the most glassy to the most crystalline forms must be examined, in order to ascertain not only the constituent minerals, but also their associations and mutual relations. Suppose this done—suppose a fairly good idea obtained of the characteristic structures and possible variations in either class—we have then to ascertain how far and in what way each representative can be modified by natural agencies. At the outset, probably, it will be found convenient to trace the processes of mineral and even of structural change without any immediate reference to the efficient cause. It soon appears that in the case of minerals, which differ in physical properties, but not in chemical composition, the one species replaces the other; the less stable gradually altering into the more stable form. Thus calcite takes the place of aragonite, hornblende of augite; one mineral may be broken up into a group, as a colloid into crystalloids, or felspar into quartz and white mica; new species may be produced by addition or subtraction of constituents from without, or by exchange from within; the replacement of silicates by carbonates, the conversion of granite into tourmaline-rock, the formation of epidote, chlorites, and serpentine; are a few among the many instances of this kind of change. By tracing the process from one part of a rock to another, numerous facts are collected and relationships ascertained. But during these investigations questions are raised in a student's mind which begin to clamour for an answer. Why does such and such a rock change, now in this way, now in that? So it becomes necessary to correlate our observations, to frame hypotheses, and open out new lines of inquiry.

So far as we know, water, pressure, heat, are the main agents in producing change in rocks, after the latter have been once deposited or solidified. In most cases it is not easy to insulate perfectly the effect of each agent, for probably every rock, which has undergone important changes, has been to some extent affected by all of them. Still many examples can be found, in which the influence of one has predominated greatly over that of the other two. For instance, it is now agreed that the structure of a slate is the result of pressure, though this probably produced a slight rise of temperature, and the rock is not likely to have been perfectly dry. Again, when a clay has been converted into an assemblage of crystalline silicates in the vicinity of an intrusive mass of granite, this is mainly the effect of heat, though the pressure cannot have been inconsiderable, and the presence of water is almost certainly essential.

Thus, in one series of examples, properly selected to illustrate the slaty rocks, we can watch the development of new minerals. We can observe which of these are readily produced and quickly attain to a considerable size, which are more slowly formed, or seem incapable, even if common, of much enlargement. We are thus led by inductive processes to conclusions as to the effects of pressure in the development of minerals in a mass of materials of a particular composition. In another series of rocks which has been affected by the heat of intrusive masses, we can watch the gradual growth of new constituents, as we proceed inward towards the originally heated mass, till we have passed from clay or slate to a crystalline aggregate of minerals, such as quartz, micas, andalusite, staurolite, and garnet. Similar effects may be noted in other kinds of sedimentary rock. Changes also are produced mainly by the action of water, but on this I need not enlarge.

Again, as another line of inquiry, the effects produced on igneous rocks by the same agents must be studied. Here the results which are more or less directly due to the action of water are often highly interesting, but as these are only indirectly connected with the main subject of this lecture, I content myself with a passing reference. With igneous rocks the effects of heat seem generally less important than with sedimentary; probably because the mineral constituents of the former are usually in a more stable condition than those of the latter, so that these also need only be mentioned; but the effects of pressure in some cases, especially with the more coarsely crystalline igneous rocks, are highly interesting and significant.

In a region such as the Scotch Highlands or the European Alps the rocks, in the process of mountain-making, have been obviously subjected, perhaps at more than one epoch, to tremendous pressures. The effect of these appears to have been sometimes a direct, sometimes a shearing fracture; that is to say, a mineral or rock, in the one case, has been crushed, as in a press, in the other, during the process of powdering it has been dragged or trailed out, with a movement somewhat similar to that of a viscous substance. As an example, let us take the effects produced in a granite by crushing. The grains of quartz are broken up; the crystals of felspar are first cracked and then reduced to powder; the mica flakes are bent, riven, and tattered. By pressure also the solvent power of water, already present in the rock, is increased; by the crushing its access to every fragment and its subsequent percolation are facilitated. Thus the black mica is often altered in various ways; the felspar dust is changed into white mica and chalcedonic quartz; the constituents are reduced in size and tend to assume a roughly parallel order; the mineral character and structure have been alike changed; a massive rock has been replaced by a foliated one; a coarse granite by a fine-grained quartzose or micaceous schist. This change can be demonstrated at every stage; it suggests that many foliated rocks—many gneisses and crystalline schists—may be igneous rocks of which both the mineral character and the structure have been modified by pressure.

We may presently see how far this inference can be justifiably extended, but, as a first step, the effect of pressure on one of the more basic igneous rocks must be considered. Let us take as an example a coarse-grained variety of the rock, which is familiar to us as basalt. It consists of a felspar, different from that of granite, of augite, of some iron oxide, and perhaps of olivine. In studying this rock we are confronted by greater difficulties, for, of the two dominant minerals, the felspar is rather less stable than that which occurs in granite, and the augite passes readily into hornblende. Thus, when the latter change occurs we are at first unable to determine whether it is due to pressure or to some other agent. Some petrologists, I believe, would not hesitate to appeal to the presence of hornblende in a rock such as we are considering as a proof that it had been modified by pressure. With this opinion I cannot agree. On examination of the numerous instances in which we are convinced that the hornblende is not an original constituent but has replaced augite, we notice that the former mineral is not constant in its characters. It may be granular in form; it may assume its usual crystalline shape; it may be more or less bladed or needle-like. Have these differences, we ask, any significance? In order to answer the question, specimens of hornblendic rocks must be sought in regions which obviously have been subjected to tremendous pressure, as is testified by the fact that every other rock has been more or less crushed or rolled out; others must be obtained from regions where the associated masses exhibit no signs of extraordinary disturbance, even though they may be more brittle than the subject of our study. In the former case the change may be reasonably attributed to pressure, in the latter it must be due to some other cause. Are hornblendic rocks from the one region similar in structure to those from the other? By no means. Where no evidence can be offered in favour of pressure, there the hornblende either retains wholly or almost wholly the outline of the mineral which it has replaced, or else assumes its normal prismatic form; but where an appeal to pressure seems justifiable, we find that the hornblende appears as unusually elongated prisms, blades, or even needles, and the structures of the rock as a whole can be readily recognized by a practised eye. The evidence for the latter statement is yet unpublished, but it will, I hope, appear before long.

So our investigations have led us thus far: that, in sedimentary rocks, in the presence of water, certain changes are mainly produced by heat, and certain by pressure. In the latter case, however, the new minerals, though very numerous individually, are generally minute; the longest diameter being seldom so much as one-hundredth of an inch. Even where this rule is broken, it is only by minerals which are proved by other experiments to be so readily developed that their presence on a large scale has no real significance. The rule holds also to some extent in the case of crystalline schists produced by the crushing of crystalline rocks, markedly in the case of those derived from granites and rocks of similar composition, but less conspicuously in those which were originally augitic or hornblendic. Though even here, where the decreased size of the minerals is less uniformly marked, new and distinctive structures are assumed.

I have spoken only of two or three common types of rocks, but it would be easy, did time permit, to support the principles enumerated, by quoting from a great variety of examples. There are, I believe, few, if any, important kinds of rock which have not been examined, and it appears to me demonstrated that, while pressure is a most important agent of change,[1] while many schists may be regarded as resulting from it, a considerable group remains, which are separated from the others by a very wide chasm, and this can only be jumped by deserting reason and trusting hypothesis.

In this last group of rocks (supposing no disturbances produced by subsequent pressure, for which, however, we can generally make allowance) the constituent minerals are commonly fairly large—say from about one-fiftieth of an inch upwards in diameter. Very many of these rocks, when studied in the field, exhibit every indication of a sedimentary origin. Though as a rule no original constituent grain can be certainly determined, though they are now crystalline, yet their general structure and association are inexplicable on any other supposition. They bear some resemblance to the sediments which have been altered by contact metamorphism, though they present different characters. These, moreover, remain invariable through considerable thicknesses of rock and over wide areas. The alteration is regional, not local, so that such rocks cannot be regarded as cases of simple contact metamorphism, even though heat may be suspected of having been an important agent in producing the change. But to another large series, including many of the rocks commonly called gneisses, the sedimentary origin is less easily attributed. Not a few of these in mineral composition correspond with granites, and sedimentary rock thus constituted, though not unknown, is rare. The minerals commonly exhibit a parallel or foliated and not seldom even a banded arrangement; in the latter case the layers of different mineral composition in their mutual relations and associations imitate with remarkable success the structure of a banded sedimentary rock. Even a dozen years since little doubt was entertained that this group also had a detrital origin. Occasionally, however, its members, when studied in the field, exhibited characteristics which were difficult to explain on any such hypothesis, and presented resemblances in habit to certain crystalline igneous rocks, from which, however, they were proved to differ in their microscopic structures.

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[1] It is probable that some changes of importance are produced in rocks by long-continued and repeated pressures, which are insufficient to give rise to crushing; but these I have passed by, because, as it seems to me, further evidence is needed before we can diagnose, with any certainty, the results of this particular disturbing cause.

In rocks which have crystallized from a state of fusion some of the mineral constituents usually exhibit their proper crystalline outlines; but in these others the same minerals had no definite shape, and were simply granular. Of this structure two types were observable: in the one the grains were elongated, in the other they were roundish in outline but slightly wavy or lobed. The former type was commonly found in the more distinctly banded varieties; the latter in the more massive and faintly foliated kinds which in hand-specimens were not readily distinguished from true granite.

As in rocks, no less than in living beings, diversities of structures are nature's record of a difference in history, it became a question whether these peculiarities were significant of origin or of environment. By prolonged observations the following results were established:—(1) That crystalline rocks, which could be proved, by their relation to others, to be truly igneous, sometimes exhibited banded structures. (2) That these structures, in certain cases, could not be attributed to any subsequent pressures or crushings, for no sign of them could be found in neighbouring rocks, which, from their composition and nature, ought to have yielded more readily. (3) That a faint foliation or banding, especially in the case of granitic rocks, could be sometimes detected in irruptive veins, in which cases the aforesaid granular structure was detected on microscopic examination. (4) That cases were occasionally found where a light-coloured granite had broken into a dark hornblendic rock, and the fragments of the latter had been gradually softened, elongated, and even drawn out into bands, together with the intruder, till they perfectly simulated, as already mentioned, a stratified mass. (5) That in certain of these cases, where a rock, exceptionally rich in hornblende, had been partially fused by a pale-coloured granite, a banded black-mica gneiss had been produced, indistinguishable, macroscopically and microscopically, from those which have been already mentioned.

It follows from these observations that the great group of crystalline rocks, which are connoted comprehensively as schists and gneisses, includes rocks which may have originated in one of three different ways:—(1) Some have once been molten, but have become solid under rather exceptional circumstances, probably having lost heat slowly, and having continued to move very gradually during the process of consolidation. (2) Others have been produced by the thorough alteration of sedimentary materials, in which a high temperature has been maintained for a long time, in the presence of water and under considerable pressure. (3) Others, again, have been the result of great pressure, which has acted on rocks already crystalline, and has produced mineral changes, sometimes to the complete obliteration of the original structure. The second and third of these groups are truly metamorphic rocks, to the first the term, strictly speaking, is not applicable.

As a rule, it is not difficult to distinguish between these three groups, and in all probability the ambiguities which still remain will be solved by patient and persevering work. Cases, no doubt, will occur on which no inference can be founded; cases where, from one cause or another, nature's record has become illegible. But to this disappointment the scholar and the archæologist has to submit equally with the geologist. Negative evidence of this kind has no disturbing power; any amount of it is outweighed by a single scrap of clear and positive testimony. It is generally a waste of time to puzzle over bad specimens; they are much more likely to produce a perplexed agnosticism than a rational faith; for a creed has its place in science no less than in theology.

I have mentioned one mode in which materials rather markedly different in mineral character may be, in a certain sense, interstratified and to some extent blended, but should add that recent researches render it highly probable that there are other modes in which mineral or chemical constituents may be differentiated in a magma which was once homogeneous. To discuss these would carry us into questions of crystallogenesis, which have no direct bearing on my present subject, though in these also the microscope has rendered the most valuable services by suggesting inferences and by testing theoretical conclusions; questions upon which so much light has been thrown by the researches of Guthrie, Lagorio, Sorby, and others; but I may refer in passing to the law established by Soret, that by a change of temperature a homogeneous solution may be rendered heterogeneous; since any compounds by which it is nearly saturated tend to accumulate in the colder parts. Gravitation also, when certain minerals are crystallizing from a magma, may cause them to rise or to sink, and in this way also heterogeneity may be produced. So when the mass of mingled fluids and solids is constrained to move, a streaked or banded structure may be the result produced; as in a process familiar to the glass-blower.

But when the geologist has learnt from the microscope to recognize differences of structure in crystalline rocks, and to appreciate their significance, he finds that a wider problem is presented to his mind, provided he has not been led by the fascinations of laboratory studies to despise or neglect work in the field. Granted that one group of rocks, covered by the term metamorphic, has undergone great changes since its members were first deposited or solidified, can these be connected with any phase in the earth's history? Have they any chronological significance? Even twenty years since few geologists would have hesitated to reply:—"None whatever: a rock may have undergone metamorphism at any epoch in the past. Muds and sands of Eocene, Jurassic, Carboniferous, Silurian, of any geological age, have been converted into crystalline schists. Proofs of some part of this assertion can be found even within the limits of the British Isles; it can be completely established within those of Europe." But during the last few years this hypothesis has been on its trial; witness after witness in its favour has been, so to say, brought into court, and has broken down under cross-examination. I can assert this without hesitation, for I have some personal knowledge of every notable instance in Europe which has been quoted in the debate. Microscopic study, combined with field work, has invariably discovered that some very important link in the supposed chain of proof is wanting, and has demonstrated without exception that these crystalline schists are very old; much more ancient always than any neighbouring rock to which a date can be assigned, if not older than the first rocks in which any trace of life has been found. It has been also demonstrated that sedimentary masses, after they have been buried deep beneath superimposed strata and exposed to great pressure, have emerged comparatively unchanged. Such rocks are most valuable as illustrations of the effects of dynamical and other agencies; but they are sufficiently distinct from the crystalline schists to indicate that the environment in the one case must have differed greatly from that in the other. The results of contact metamorphism prove that heat is an important agent of change; but as these also present their own marked differences, they fail to afford a complete solution of the problem.

Moreover, among ordinary sedimentary rocks, we cannot fail to notice that, as a rule, the older the rock the greater the amount of mineral change in its constituents. A good illustration of this is afforded by the Huronian system of North America, the rocks of which are rather older than the Cambrian of this country. Some of them, while still retaining distinct indications of a sedimentary origin, have become partially crystalline, and supply examples of a transition from a normal sediment to a true crystalline schist. Even the older Palæozoic rocks almost invariably exhibit considerable mineral changes, though with them it is only on a microscopic scale. Hence, taking account of all these results, we seem to be forced to the conclusion that the environment necessary for changing an ordinary sediment into a crystalline schist existed generally only in the earliest ages, and but very rarely and locally, if ever, since Palæozoic time began.

Further, in regard to those peculiar structures which, as already stated once led geologists to consider certain rocks, really of igneous origin, as metamorphosed sediments; they also appear to have been much more frequently produced in the earliest ages. They are common in association with the ordinary crystalline schists; they are found, so far as I know, rarely, if ever, with little altered sediments. The microscopic study of the coarser stratified rocks—grits, sandstones, &c.—lends some support to this view, by showing that, as we go back in time, a larger proportion of their materials, *cæteris paribus*, has been derived from crystalline rocks, and that even the fragments, obviously of sedimentary origin, exhibit signs of some mineral change; that is to say, the mudstones and sandstones in the later grits are apt to be represented in the earlier by phyllites and quartzites.

So the results of microscopic study, in alliance with, not divorced from, work in the field, lead us to the conclusion that in the early ages of this globe's history conditions generally prevailed which became gradually, perhaps even rapidly, rare and local; or, in other words, that in geology the uniformitarian doctrine must not be stated in terms wholly unlimited, though, since this was first enunciated by Lyell, nothing has been discovered to shake our faith in its general truth, or to resuscitate the catastrophic hypothesis which it replaced. But geologists are forbidden by students of physics to regard the universe as a "self-winding clock." The latter affirm, and the former frankly admit, that this globe through long ages has been losing heat by radiation; that there was a time when the temperature of its surface far exceeded that of molten iron: a temperature which now would be reached only at a depth of many miles. If this be so, the conditions under which rocks were formed on the surface of the globe in early days must have been very different from those which subsequently prevailed. Suppose, for example, this surface to have been just white-hot—namely, at a temperature much below that at which most, if not all lavas, consolidate. In that case the ocean would be vapour, and the weight of the atmosphere would be augmented by that of a shell of water of the area of the globe, and two miles in thickness; or, in other words, the atmospheric pressure would be about 350 times its present amount. If so, even a lava-flow would consolidate under a pressure equivalent to that of some 4000 feet of average rock. But after the surface temperature had become low enough to permit the seas to be gathered together, and the atmospheric pressure had become normal; after rain and rivers, winds and waves, had commenced their work; after sediments, other than the "dust and ashes" of volcanoes, had begun to accumulate; still these at a short distance below the surface would find a very different environment from that which now exists. It has been proved by Lord Kelvin that at the end of about one twenty-fifth portion of the whole time which has elapsed since the first solidification of the earth's crust, the underground temperature must have risen at nearly six times its present rate. To reach a zone, the general temperature of which is 212° F., it would now be necessary to descend, as a general rule, at least 8200 feet, and probably rather more. But in those early days the crust would have been at this temperature at a depth of about 1600 feet, and at 10,000 feet it would have risen to 1050° F., instead of 250° F., which now would be exceptionally high. To this depth many rocks, both in Palæozoic and later ages, have been buried, and they have emerged practically unchanged. Hence it follows that the latter temperature is comparatively ineffective; the former, however, could not fail to facilitate mineral changes and the development of coarsely crystalline structures.

These changes, these structures, have been produced in sedimentary rocks in the immediate neighbourhood of a large mass of intrusive igneous rock, such as a coarse granite. To what temperature the former have been raised cannot be ascertained. Suppose, however, it were 1500° F., which probably is not a very erroneous estimate, this temperature, at the epoch mentioned, would be found at a depth of 15,000 feet. It is now, probably, at least 15 miles beneath the surface. In other words, the zone at which marked mineral changes could be readily produced, quickly sank, and has long since reached a depth practically unattainable. The subterranean laboratory still exists, but the way to it was virtually closed at a comparatively early period in the earth's history.

Another effect of this rapid downward increase of temperature must not be forgotten. When it amounted to 1° F. for every 10 feet of descent, a temperature of 2000° F. would have been reached at a depth of not quite four miles. This would be rather above the melting-point of many rocks, if they were at the surface; so that, even under the pressure, they would be either very near it or imperfectly solid. If the thickness of the crust were only about four miles, flexures would be readily produced, and the effects of tidal stresses would be considerable; but even if the earth had become solid as a whole, there would have been large masses of rock, comparatively near to the surface, in an unstable condition, and thus liable locally to slow deformations, displacements, fluxional movements, and intrusion into other masses already at a high temperature, with the result of partial melting down and mutual reactions. Disturbances such as these, slow, but constantly recurring, would produce structures imitative of stratification. It is a remarkable coincidence, to say the least, that these structures are characteristic of Archæan rocks, and are extremely rare, if ever present, in those of later date.

But some geologists are so rigidly uniformitarian as to shrink from admitting that any portion of the earth's original crust can possibly be preserved. "Take time enough," they say, "and the changes can be made." But will time alone suffice for every kind of change? How long will it be before gunpowder explodes at blood-heat? But passing over this obvious difficulty, we may ask: Is there time enough? So geologists once thought, as fancy travelled back over endless æons. But they are checked by the physicist: "earth and sun alike," he affirms, "are masses subject to the laws of radiation; these countless millions of years of which you dream will bring you to a period when not only the earth, but also the whole solar system, was nebulous. All the history of your planet, physical as well as vital, so far as it can be covered by your records, must be compressed into a very moderate number of millions of years, for we have to consider the possibilities not only of a cooling earth, but also of a cooling sun." If this be so, and it seems difficult to dispute the decision; if we are forbidden to look back along "the corridors of time" till they vanish in the perspective of infinite distances, it becomes more and more probable that the whole volume of the earth's history is within our reach, and that its opening chapters will some day be deciphered.

The progress which has been made since the microscope was pressed into the service of geology augurs well for the future, if we work in a spirit of scepticism and a spirit of hope. Of scepticism, lest we trust too much either in ourselves or in even the princes of science; for experience proves that the seductive charms of phantom hypothesis may lead all alike astray from the narrow path of truth into the morasses of error. Of hope, for experience also proves that by patient labour and cautious induction many an illusion has been dispelled and many a discovery been made. Our eyes must soon grow dim, our hands become nerveless, but other workers will be found to take warning from our mistakes and to profit by our toil. The veil which shrouds the face of Nature may be never wholly withdrawn, but its fringe has been already raised; even in our own generation so much has been accomplished that the hope may be indulged of at last learning something of the history of these earliest ages, when the earth had but lately ceased to glow, and when the mystery of life began.

THE LADIES' CONVERSAZIONE OF THE ROYAL SOCIETY.

THE Ladies' *Conversazione* of the Royal Society took place on the evening of June 15 last, and in every way was a distinct success, the attendance being the greatest on record, and all the available space both for the guests and exhibits being fully occupied. The exhibits, although they included a few that were shown at the last *soirée*, were for the most part new, and the following is a brief summary of the most noticeable of them:—

Dr. H. Hicks, F.R.S., showed the remains of a mammoth found in Endsleigh Street, in March last, at a depth of only 22 feet. The bones were of enormous proportions, and in their proximity was discovered a tusk which was estimated to have been 12 feet in length.

A series of enlarged transparent sections of the fossil plants of the Coal-measures were exhibited by Prof. W. C. Williamson, F.R.S.

Most interesting were the water-colour drawings of Greek temples, &c., by Mr. F. C. Penrose, which illustrated his current investigations on the astronomical orientation of ancient Greek temples. The drawings included those of the Propylæa, the Temple of the Wingless Victory, Parthenon, west and east fronts of the Parthenon, north portico of the Erechtheum, east portico of the Theseum, and the Temple of Jupiter Olympius.

Mr. W. M. Flinders Petrie showed some excellent water-